DEFENCE R&D DÉFENSE

Noise Measurements at Cape Race in Support of East Coast High Frequency Surface Wave Radar

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Abstract

In support of the operation of the east coast High-Frequency surface wave radar (HFSWR) systems, a continuous measurement of noise and interference data in the frequency band of 3-6 MHz was carried out at Cape Race, Newfoundland between August 1, 1998 and May 10, 2000. A procedure called the "minimum of median" was developed to estimate the noise factors from the measured data. The results of the estimation are presented in this report. This estimation showed that (a) nighttime noise power level could be as much as 24.1 dB above daytime noise level; (b) daytime noise level could be sustained for more than 10 hours during the summer, but only for about 6 hours during the winter. The estimated noise factor was then compared the CCIR noise factor for a quiet site [1]. From this comparison, we found that (a) the daytime noise power level could be as much as 6.08 dB lower than the corresponding CCIR noise level, and (b) the nighttime noise level could be as much as 6.72 dB higher than the corresponding CCIR noise level. The transitions from daytime to nighttime or from nighttime to daytime in the measured and CCIR noise data agreed mostly with each other. One exception was that, in the falls of both 1998 and 1999, the nighttime-to-daytime transition in the measured noise data was about two hours earlier.

Résumé

Pour supporter les opérations du radar décamétrique à onde de surface de la côte Est, des mesures continues de bruit et d'interférences dans la bande de fréquence 3-6 MHz ont été effectuées à Cap Race, Terre-Neuve entre le premier août 1998 et le 10 mai 2000. Un procédé appelé le médian minimum a été développé pour estimer le factor de bruit des données mesurées avec le radar. Les résultats des estimés sont présentés dans ce rapport. Ces estimés montrent que; a) la puissance du bruit nocturne peut être 24.1 dB au dessus du niveau de bruit de jour; b) le niveau de bruit de jour peut duré plus de 10 heures durant l'été, mais seulement six heures durant l'hiver. Le valeur estimé du facteur de bruit été comparé au facteur de bruit du CCIR pour un site tranquille [1]. De ces comparaisons, nous trouvons que; a) le niveau de puissance de bruit de jour peut être 6.08 dB plus bas que celui correspondant au niveau de bruit du CCIR et; b) le niveau de bruit nocturne peut être 6.72 dB plus grand que le niveau correspondant du CCIR. La transition du jour à la nuit ou de la nuit au jour dans les données de bruit mesurées et du bruit du CCIR est largement en accord. Une exception a été, dans l'automne de 1998 et 1999, la transition de nuit au jour dans les données mesurées a été deux heures plus tôt.

Executive Summary

In collaboration with Raytheon Canada Limited, the Department of National Defence has recently installed two High Frequency surface wave radar (HFSWR) systems on the east coast at Cape Bonavista and Cape Race, Newfoundland. These two systems operate in the frequency band between 3 and 6 MHz, and are capable of detecting ships and low-flying aircraft over a sea surface at distances well beyond the horizon of a microwave radar. The radar performance, however, depends critically on the external noise power level at the input of the receiving antennas. In support of the operation of the two HFSWR systems, a continuous measurement of noise and interference in the frequency band of 3-6 MHz was carried out at Cape Race between August 1, 1998 and May 10, 2000. A procedure called the "minimum of median" was developed to estimate the noise factors from the measured data. This report presents the results of the estimation.

The estimated noise factors showed that:

1. As expected, there was a significant diurnal variation; nighttime noise power level could be as much as 24.1 dB above daytime noise level.

2. There were also some seasonal variations. Daytime noise level could be sustained for more than 10 hours during the summer, but only for about 6 hours during the winter. Daytime noise level showed very little seasonal variations. Nighttime noise level, however, was higher during the summer, and lower during the winter. The biggest difference in the nighttime noise levels between the summer and winter was 7.38 dB at the radio frequency (RF) of 5 MHz.

The estimated noise factor was then compared with the CCIR noise factor for a quiet site [1]. From this comparison, we found:

1. The measured noise factor during daytime was generally lower than the corresponding CCIR noise factor; the biggest difference between the daytime noise factors was 6.08 dB at the RF of 6 MHz in the fall of 1999.

2. The measured noise factor during nighttime was generally higher, likely due to a broader bandwidth used in our noise measurement. The biggest difference between the estimated and CCIR noise factors at night was 6.72 dB at the RF of 4 MHz in the summer of 1999.

3. Daytime-to-nighttime or nighttime-to-daytime transitions exhibited in the noise data mostly agreed with each other. One exception was that, in the falls of both 1998 and 1999, the nighttime-to-daytime transitions in the measured noise data appeared to come about two hours earlier.

With a lower noise factor, the HFSWR systems achieve their best performance during daytime hours. Furthermore, this best performance is sustained longer during the summer

than during the winter. The estimated noise factor indicates that this best performance could be sustained for four hours longer during the summer than during the winter. During daytime hours, the estimated noise factor indicates that we could actually get a slightly better performance than what the CCIR noise factor indicates. At night, however, the performance of the two radar systems could be degraded due to the presence of interference. The earlier nighttime-to-daytime transition in the fall, as observed in the falls of 1998 and 1999, is beneficial to the radar operation in that the radar systems could achieve their daytime performance for about two hours longer.

Leong, H, Dawe, B. and Power, D. 2000. Noise Measurements At Cape Race in Support of East Coast High Frequency Surface Wave Radar. DREO TM 2000-089. Defence Research Establishment Ottawa.

Sommaire

En collaboration avec Raytheon Canada Limited, le Département de Défense Nationale a récemment installé deux systèmes radar décamétriques à onde de surface sur la côte Est à Cap Bonavista et Cap Race, Terre-Neuve. Ces deux systèmes opèrent dans la bande de fréquence entre 3 et 6 MHz, et sont capable de détectées des bateaux et des avions volant au-dessus de la surface de l'océan à des distances bien au-delà de l'horizon d'un radar microonde. La performance radar, cependant, dépend sévèrement du niveau de bruit extérieur à l'entrée de l'antenne réceptrice. Pour supporter les opérations du radar décimétrique à onde de surface de la côte Est, des mesures continues de bruit et d'interférences dans la bande de fréquence 3-6 MHz ont été effectuées à Cap Race, Terre-Neuve entre le premier août 1998 et le 10 mai 2000. Un procédé appelé le médian minimum a été développé pour estimer le factor de bruit des données mesurées avec les radars. Ce rapport présente les résultats de ces estimations.

Les facteurs de bruit estimés montrent que :

1. Comme supposée, il y a une grande variation durant le jour; le niveau de puissance de bruit nocturne peut être 24.1 dB au-dessus du niveau de jour.

2. Il y avait aussi quelques variations saisonnières. Le niveau de bruit de jour peut durée plus de 10 jours durant l'été, mais seulement 6 heures durant l'hiver. Le niveau de bruit de jour a montré peu de variations pendant les saisons. Le niveau de bruit nocturne, cependant, était plus élevé durant l'été, et plus bas durant l'hiver. La plus grosse différence dans les niveaux de bruit nocturnes entre l'été et l'hiver a été 7.38 dB à la fréquence radio de 5 MHz.

La valeur estimée du facteur de bruit été comparé au facteur de bruit du CCIR pour un site tranquille [1]. De ces comparaisons, nous trouvons que :

1. Le valeur mesurée du facteur de bruit durant le jour est généralement plus basse que celle correspondant au CCIR; la plus grosse différence entre le facteur de bruit durant le jour a été 6.08 dB à la fréquence de 6 MHz dans l'automne de 1999.

2. La valeur mesurée du facteur de bruit nocturne est généralement plus grande, probablement due à la bande de fréquence plus grande utilisée dans nos mesures de bruit. La plus grande différence entre les estimés et les facteurs de bruit du CCIR durant la nuit a été 6.72 dB à une fréquence de 4 MHz durant l'été de 1999.

3. Les transitions du jour à la nuit ou de la nuit au jour dans les données de bruit mesurées sont largement en accord les uns avec les autres. L'automne de 1998 et 1999 est cependant une exception car la transition de nuit au jour dans les données mesurées semblent apparaître deux heures plus tôt.

Avec un facteur de bruit plus bas, les systèmes radar décimétrique à onde de surface ont leurs meilleures performances durant les heures du jour. De plus, cette meilleure performance dure plus longtemps durant l'été. Les facteurs de bruit indique que cette performance pourrait

durée 4 heures de plus durant l'été comparé à l'hiver. Durant la journée, les valeurs estimées des facteurs de bruit indique que nous pourrions actuellement obtenir une performance légèrement meilleure que ceux du CCIR. Durant la nuit, cependant, la performance des deux systèmes radars pourrait diminuée due à la présence des interférences. Les transitions antérieures de la nuit au jour dans l'automne de 1998 et 1999 sont bonnes vue d'une perspective des opérations radars; les systèmes radars avaient leurs performance de jour durant deux heures de plus.

Leong, H., Dawe, B. and Power, D. 2000. Noise Measurements At Cape Race in Support of East Coast High Frequency Surface Wave Radar. DREO TM 2000-089. Defence Research Establishment Ottawa.

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Acknowledgements

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1. Introduction

In collaboration with Raytheon Canada Limited, the Department of National Defence has recently installed two High Frequency surface wave radar (HFSWR) systems on the east coast at Cape Bonavista and Cape Race, Newfoundland. These two radar systems operate in the lower end of High Frequency (HF) band between 3 and 6 MHz, and are capable of detecting ships and low-flying aircraft over a sea surface at distances that are well beyond the horizon of a microwave radar. This detection capability, however, depends critically on the external noise power at the input of the receiving antennas. In addition to radar frequency (RF) dependence, the external noise power level also varies significantly with the time of a day due to the influence of the ionosphere. During daylight hours, there is a presence of D layer in the ionosphere, and the D layer absorbs signals from other sources (such as lightning), thus reducing the ambient noise at the inputs of the radar antennas. During nighttime hours, the D layer is absent. The signals in the HF band can thus penetrate through the lower altitudes where D layer is during the day and be refracted off the higher layers of the ionosphere (e.g., F layer). These signals can propagate via the skywave mode from sources at long distances, thus increasing the ambient noise input to the radar antennas. Depending on the geographical location of the radar site, the nighttime noise level could be anywhere between 15 and 30 dB above the daytime noise level.

A well designed radar receiver should be external noise-limited to maximize the detection range of the radar. Hence, the radar detection performance, particularly at night, hinges on the power level of external ambient noise. To determine the detection capability of the HFSWR systems, we need to know the variation of the noise power level with time and with radar frequency.

The noise model [1] supplied in 1985 by the International Radio Consultative Committee (CCIR, now renamed to the International Telecommunications Union, or ITU) serves as a benchmark for the prediction of the radar performance. However, the model is based on the interpolation of noise data measured at selected geographical locations in the world, and the modeled noise data may not be sufficiently accurate for a specific radar site.

In support of the operation of the HFSWR systems, we carried out a continuous measurement of the noise and interference power level at Cape Race, Newfoundland, for the period between August 1, 1998 and May 10, 2000. In this report, we describe the noise monitor system that was used in the measurement, and the procedure that we used to estimate the noise power level from the measured data. This report then presents the results of the noise estimates, and compares the noise estimates with the corresponding CCIR noise data. We should point out that, although the noise measurement was made at Cape Race only, which is only about 226 km from Cape Bonavista, the results presented in this report should be valid for both radar sites.

2. Noise Monitor System Configuration

The noise monitor was set-up at the center of the radar site at Cape Race (Latitude=46.65° North; Longitude=53.08° West). Figure 1 shows the location of the noise monitor antenna relative to the main building of the radar site and the transmit and receive antennas of the radar. The noise monitor antenna was a 23 foot, Shakespeare model 33, SSB fiberglass monopole antenna, located at a distance of about 160 feet from the back of the main building. The antenna was installed with a base of 32 copper radials (#12 wire, 15 m long) as a ground screen.

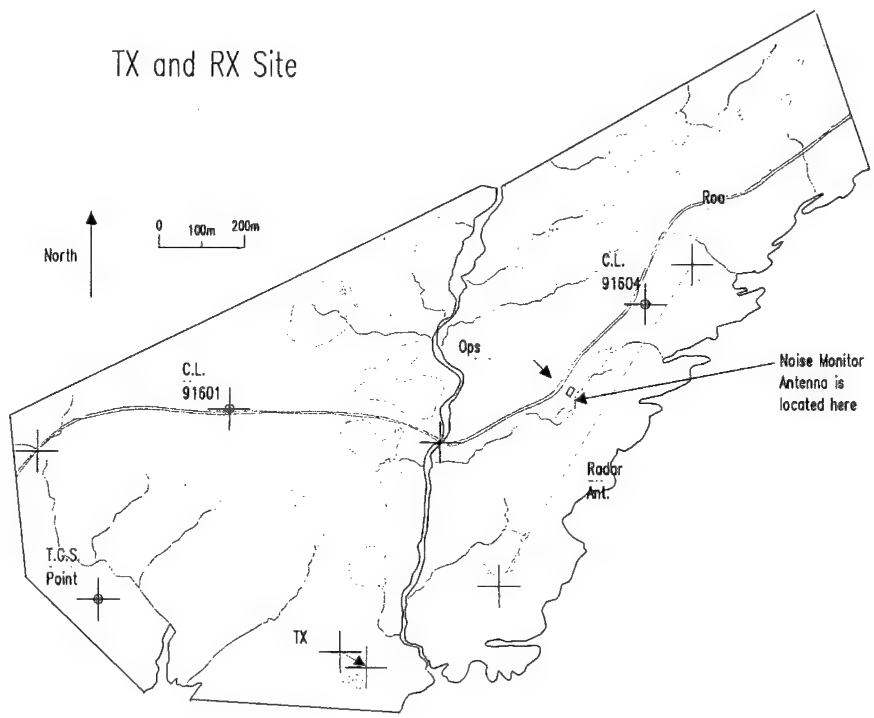

Figure 1. *Location Of Noise Monitor Antenna Relative To HFSWR Transmit And Receive Antennas*

Figure 2 shows the system configuration of the noise monitor. In addition to the 23 foot monopole antenna, the noise monitor system consisted of a high-pass filter, a pre-amplifier, a Rohde & Schwarz ESH3 receiver and a standard PC compatible computer system. The high-pass filter had a cut-off frequency of 1.8 MHz, and was used to reject the interference of low frequency broadcast radio signals. A mini-circuits ZHL-1A amplifier was connected as a pre-amplifier to improve the sensitivity of the noise monitor. The pre-amplifier provided an average gain of 18.5 dB so that the input to the Rohde & Schwarz ESH3 receiver was not internal noise-limited. The computer was connected to the ESH3 receiver using a GPIB

interface, and the computer was then connected to an FTP server via an Ethernet interface. The measured noise data was thus available remotely from the FTP connection.

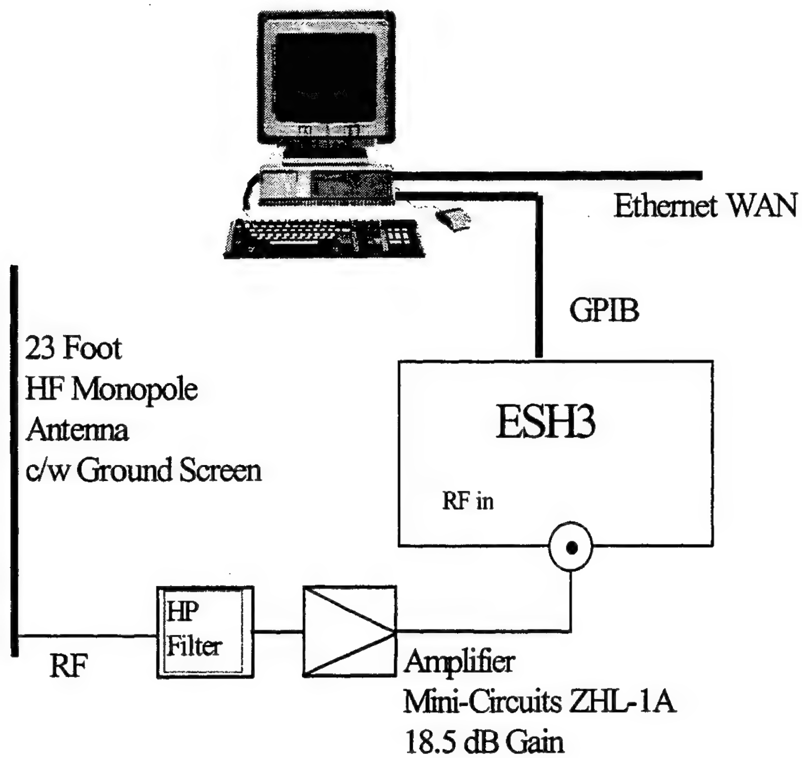

Figure 2. *Noise Monitor System Configuration*

The HFSWR systems at Cape Race and Cape Bonavista were designed to operate at a nominal radio frequency between 3.5 and 5.5 MHz. In support of the radar systems, we limited the overall bandwidth of the noise monitor to an interval between 3 and 6 MHz. For each hour of a day, the noise monitor scanned the frequency band of 3 to 6 MHz with a frequency step-size of 10 kHz. Hence, we obtained an hourly measurement of the noise and interference power levels at the RFs of 3.00, 3.01, 3.02, ..., 6.00 MHz. The measurement bandwidth of the noise monitor was chosen to be 10 kHz. This measurement bandwidth is larger than the bandwidths of most communication signals present in the HF band. However, since the radar system has bandwidths typically in the order of tens of kilo-Hertz, it is small enough so that the measurement could give an indication of the noise and interference power level expected at the radar receivers. For the measurement at each RF, the noise monitor used an integration time of 2 seconds, followed by a gap of 2 seconds before the measurement for the next RF. For the 301 measurements across the frequency band, the noise monitor hence used a duration of 1204 seconds or slightly more than 20 minutes. An ionosonde was also operated at the radar site at Cape Race. To avoid the interference from the ionosonde, the ionosonde was scheduled to operate at the top of the hour for about 5 minutes, and the noise monitor to activate at a quarter past the hour. In summary, the noise monitor scanned the band of 3-6

MHz once every hour and the computer automatically logged the noise power measurement once per hour.

The measured data were recorded in a computer file daily between August 1, 1998 and May 10, 2000, except during power outages, short-term continuous testing of radar and/or ionosonde, and after damages to the noise monitor antenna due to lightning and/or thunderstorm. Occasionally, there were also hardware problems with the noise monitor, such as computer problems and the failure of the pre-amplifier. The measured data were monitored regularly to ensure that the noise monitor operated properly. In case of damages to the antenna and other hardware problems, the noise monitor was re-calibrated after each problem was resolved. Table 1 lists the dates in each month for which the data are available, along with comments on why data are missing in some months.

Table 1. **Noise Monitor Data Availability**

Dates for Which Data Are Available	Number of Days for Which Data Are Available	Comments
Aug 01-23, 27-31, 1998	28	Power outage, Aug 23-27
Sept 01-24, 28, 1998	25	Hardware failure, Sept 25-27
Oct 01-13, 20-31, 1998	25	Computer and power failure, Oct 14-19
Nov 01-30, 1998	30	Temporary power outage, Nov 16 and 20
Dec 01-31, 1998	31	Antenna damaged Dec 08, 1998-Jan 13, 1999;
Jan 01-31, 1999	31	Damage detected and fixed on Jan 13, 1999.
Feb 01-28, 1999	28	
Mar 01-31, 1999	31	Power outage, Mar 19
Apr 8-9, 12-13, 28-30, 1999	7	Pre-amp failed.
May 01-31, 1999	31	
Jun 01-30, 1999	30	
Jul 01-31, 1999	31	
Aug 01-31, 1999	31	
Sept 01-18,20-21,24-25,27-30, 1999	24	Power outages
Oct 01-15, 1999	15	Pre-amp failed
Nov 03-30, 1999	28	
Dec 01-31, 1999	31	
Jan 02-31, 2000	30	Y2K shut down on Jan 01, 2000
Feb 01-29, 2000	29	
Mar 01-31, 2000	31	
Apr 01-30, 2000	30	
May 01-10, 2000	10	Operation stopped on May 10

The noise monitor has been calibrated using a procedure described in Appendix A. This includes the calibration of the monopole antenna and pre-amplifier, and the correction of the cable attenuation for the different radio frequencies within the 3-6 MHz band. The calibrated output power from the noise monitor, p_{na}, can be converted into a noise factor, f_a, using Equation (1) according to the CCIR definition [1]:

$$f_a = p_{na} / kT_0 b \tag{1}$$

where k = the Boltzmann's constant = 1.38×10^{-23} J/K
T_0 = standard temperature[1] = 290 K
b = bandwidth of the noise monitor = 10 kHz

In decibel scales, Equation (1) becomes

$$F_a = P_{na} - 10Log(kT_0 b) \tag{2}$$

The output power p_{na} is in Watts in Equation (1), and correspondingly, the output power P_{na} is in dBW in Equation (2). The calibrated output power from the noise monitor is actually provided in dBmW. Hence, we need to convert it into dBW by subtracting 30 dB before using Equation (2) to calculate the noise factor from the measured noise data.

Figure 3 shows typical plots of the Rodhe and Schwarz ESH3 scans at midday and midnight at Cape Race, Newfoundland. During midday, the D layer absorbs signals from other sources at long distances, and therefore, the radar operation environment is relatively quiet. During midnight, however, the D layer is absent, and signals in the HF band can propagate via skywave mode from other sources at long distances. Figure 3 clearly shows the presence of many interfering signals in the frequency band from the scan at midnight.

[1] There is a small difference in the temperature we use here and the temperature used by CCIR. CCIR uses a temperature of 288 K in [1], whereas we use a standard temperature of 290 K. This difference, however, is really negligible, adding about -0.03 dB only to the measured data.

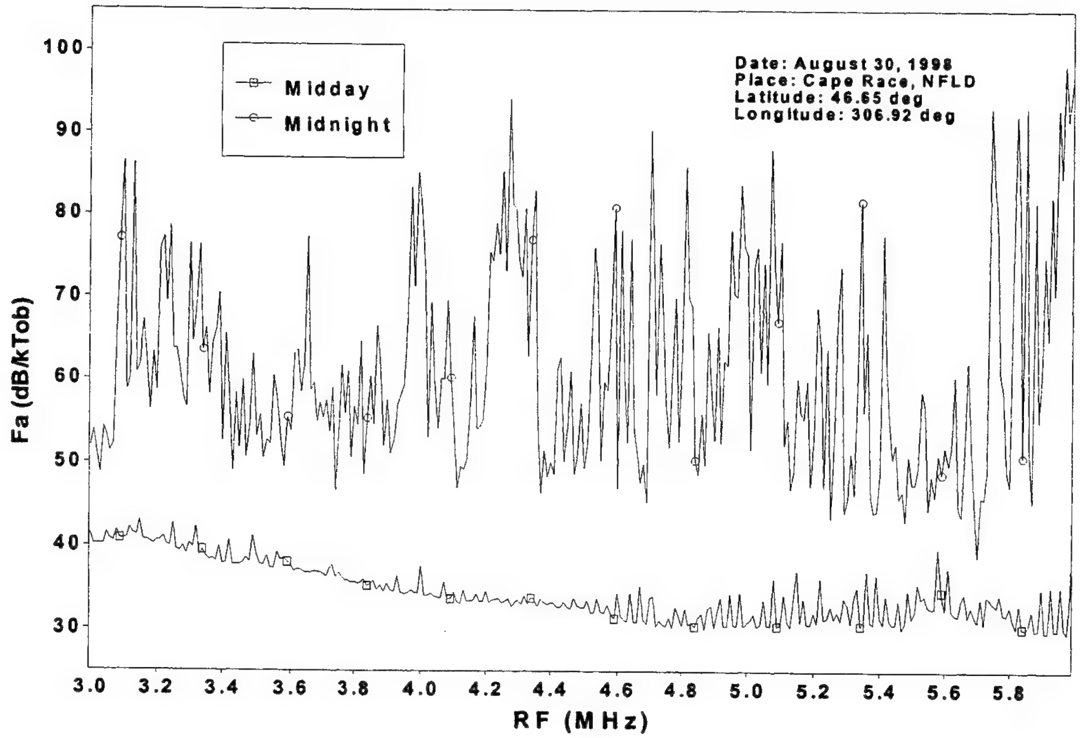

Figure 3. *Typical Plots Of Rodhe And Schwarz ESH3 Scans At Midday And Midnight At Cape Race, Newfoundland*

One of the problems encountered while setting up the noise monitor was that the ESH3 receiver was initially internal noise-limited during daytime hours. This problem was resolved by the addition of the ZHL-1A pre-amplifier. The pre-amplifier provided an averaged gain of 18.5 dB across the frequency band to boost up the input to the ESH3 receiver. Figure 4 shows the internal noise level of the ESH3 receiver measured with a matching 50-Ohm input resistor in replacement of the monopole antenna. This internal noise level is compared with the daytime noise level that was shown in Figure 3. As shown in Figure 4, the ESH3 receiver is now clearly externally noise-limited, and the daytime noise power level is well above the internal noise power level.

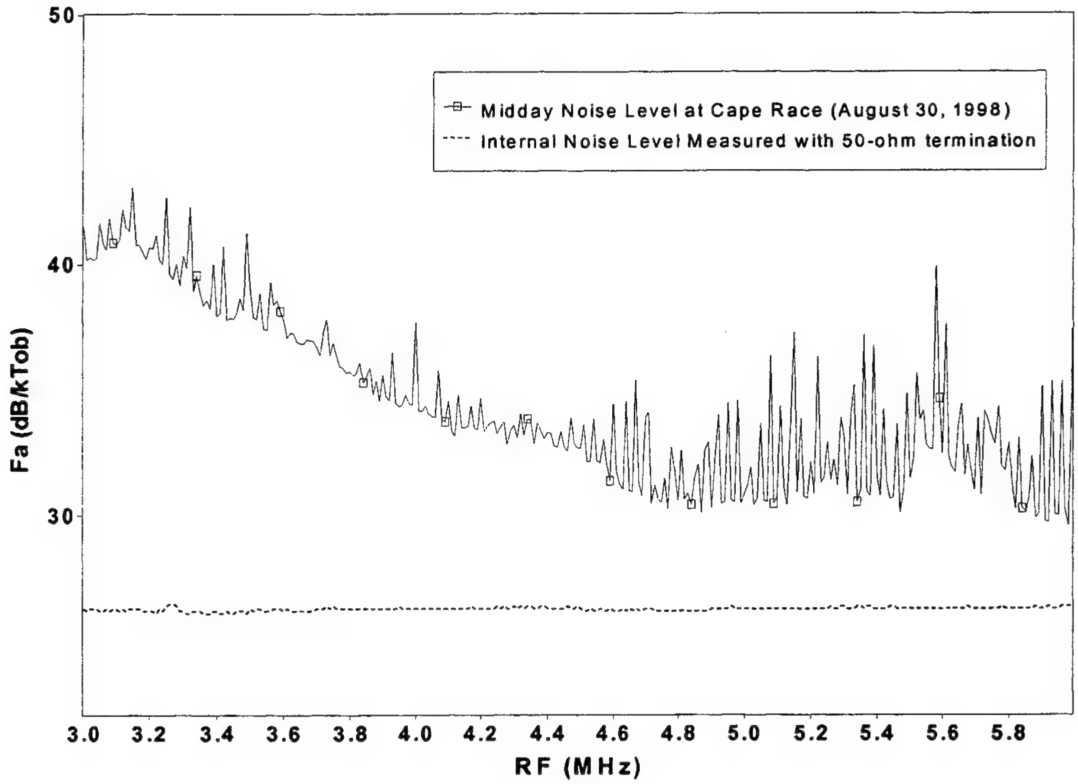

Figure 4. *Comparison Of Daytime Noise Power Level With Internal Noise Power Level Measured With A 50-Ohm Input Resistor Termination*

3. Noise Factor Estimation Procedure

The nighttime noise data were obviously contaminated with many interfering signals. To estimate the noise floor at different selected frequencies, we used a procedure called "minimum of median", as described below:

1. Obtain the median of the measured data at each frequency bin and at each hour of a day over a specified season of a year;

2. Take the minimum of the median over a specified frequency interval (bandwidth) to estimate the noise figure at the upper bound of that interval.

For our set of data, we have chosen a bandwidth of 1 MHz, i.e., we take the minimum of the median over the frequency interval of 3-4 MHz, 4-5 MHz, and 5-6 MHz, and we obtain noise estimates at the radio frequencies of 4, 5, and 6 MHz.

The rationale for the procedure is as follows. The noise power level is known to have significant diurnal changes. Hence, we maintain the hourly variation of the noise data, and we take the median of the measured noise data at each frequency bin and at each hour of a day over a specified season of a year. By taking the median at each radio frequency bin, we also maintain the variation of the noise and interference power levels across the frequency band. However, since the interference normally dominates the external noise, and some interfering signals may appear on a daily basis at night in certain frequency bins, the median would not provide a true representation of the noise floor. In order to provide a better estimate of the noise floor, we take the minimum of the median over selected frequency intervals. In our case, we choose the frequency intervals to be between 3 and 4 MHz, 4 and 5 MHz, and 5 and 6 MHz. The noise level generally decreases with frequency in the frequency band of 3 to 6 MHz. Hence, we consider the minimum in each frequency interval as an estimate of the noise power level at the upper bound of that frequency interval.

Traditionally, the season of a year is classified as spring from March to May, summer from June to August, fall from September to November, and winter from December to February. CCIR (now ITU) has taken this traditional classification in the noise model in [1]. Here, we take the same classification, and show the noise variations over the four seasons.

4. Results of Noise Factor Estimation

The data available from the noise monitor are grouped into the different seasons according to the classification described in Section 3. There are six complete seasons of data available: fall and winter, 1998, and spring, summer, fall and winter, 1999. In this report, we focus our analysis on the data collected during these six seasons. On the days when there were hardware problems or power outages, we exclude the data from the analysis.

Figure 5(a-f) shows the diurnal variations of the noise factors estimated from the measured data for the six seasons, using the estimation procedure described in Section 3. For all six seasons, the noise estimates exhibit a marked variation between daytime and nighttime hours. The noise level is significantly higher at night, and drops by as much as 20 dB during daytime. Note that, in Figure 5, the time axis (horizontal axis) is expressed in universal time code (UTC), or Greenwich time. The local Newfoundland time is 3.5 hours behind Greenwich time, except during the summer daylight saving time when the local time is only 2.5 hours behind.

In addition to the significant diurnal variation, the noise estimates also show some seasonal variations of the noise factors. One observation we can make from Figure 5 is the duration of the daytime period, in which the noise level is the lowest. The daytime period is sustained, on average, for more than 10 hours during the summer, whereas the same period is sustained for only about 6 hours during the winter. In the daytime period, the HFSWR systems achieve the best detection performance. Hence, we expect that the radar systems achieve this best detection performance for a longer period during the summer than during the winter.

From Figure 5, we can also observe, from the limited amount of data, that the noise factors in the same season from different years exhibit similar variation patterns. The noise factors in Figure 5(a) for the fall of 1998 are remarkably similar to those in Figure 5(e) for the fall of 1999. The noise factors in Figure 5(b) for the winter of 1998 are also very similar to those in Figure 5(f) for the winter of 1999. One exception to this similarity is in the noise factor at 6 MHz during daytime hours. It is not clear why the noise factors at 6 MHz during the daytime hours in the fall and winter of 1998 were higher than those in 1999. One possible reason was probably due to the number of hardware failures and power outages we had during the fall and winter of 1998. Nevertheless, the similarity in the noise factors seems to indicate that the variation pattern is maintained year after year. This indicates that the measured noise figures can be used to predict the performance of HFSWR systems in future operations.

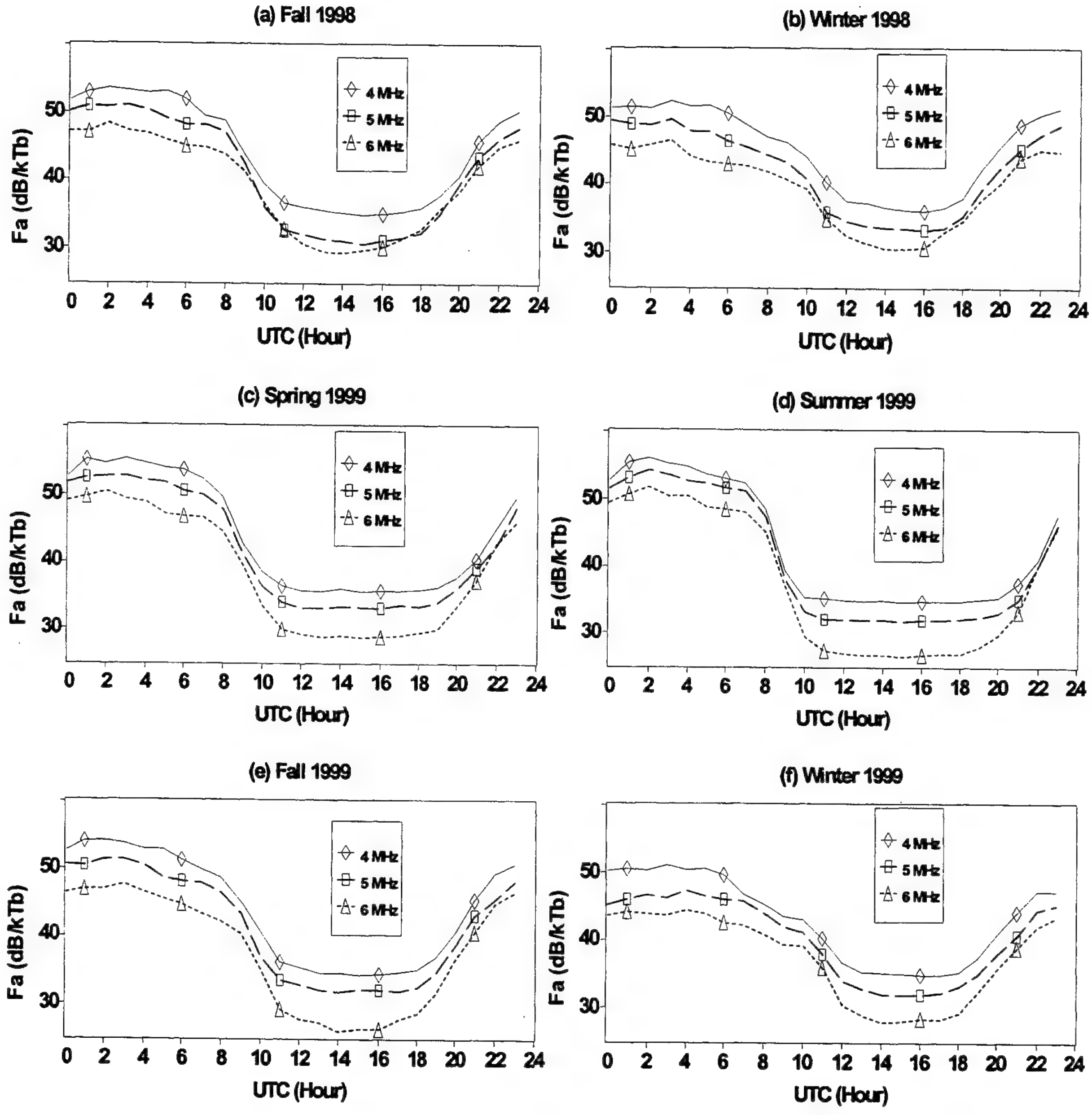

Figure 5. *Composite Plot Of Measured Noise Factors At 4, 5 And 6 MHz At Cape Race In Six Consecutive Seasons*

The third and fifteenth UTC hours correspond approximately to local midnight and midday, respectively. The estimated noise factors in 1999 are tabulated in Tables 2 and 3, respectively for the third and fifteen UTC hours at the radio frequency of 4,5 and 6 MHz to show the seasonal variation of the noise factors at midnight and midday. From Table 2, we can observe that the noise factor at midnight was the highest during the summer and lowest during the winter. The difference between the noise factors at midnight during the summer and during the winter is 4.18, 7.38 and 6.77 dB, respectively at the radio frequencies of 4, 5 and 6 MHz. From Table 3, however, we observe that there was little seasonal change in the noise factor at midday for the three radio frequencies. The difference between the maximum and minimum noise factors at midday from the four seasons is only 1.30, 1.56 and 2.42 dB, respectively at the radio frequencies of 4, 5 and 6 MHz.

Table 2. Estimated Noise Factor (dB/kT_0b) At Midnight (3rd UTC Hour) In 1999

Season \ RF (MHz)	4	5	6
Spring	55.38	52.89	49.47
Summer	55.32	53.69	50.52
Fall	53.79	51.44	47.75
Winter	51.14	46.31	43.75

Table 3. Estimated Noise Factor (dB/kT_0b) At Midday (15th UTC Hour) In 1999

Season \ RF (MHz)	4	5	6
Spring	35.59	33.24	28.74
Summer	34.59	31.68	26.42
Fall	34.29	32.19	26.32
Winter	35.03	31.85	27.97

The seasonal difference in the noise factors at midnight is in part due to the lower noise factor during the winter. A main source contributing to the noise figure is due to lightning. During the winter, lightning activities are considerably less than during the summer. Hence, at midnight, the noise factor is lower during the winter and higher during the summer. At midday, the presence of D layer absorbs most of the contribution from lightning. Hence, there is very little seasonal change in the noise factor, in spite of the fact there are generally more lightning activities during the summer.

The noise factors reported here have been measured using an omni-directional monopole antenna. It has been reported from the radar measurements on the east coast that the noise floor in the radar receivers at night exhibits a certain directionality, with the maximum noise power level at the direction of the Equator [2]. In light of the discussion above, it would be interesting to investigate whether this directionality is more pronounced during the summer than during the winter.

From Tables 2 and 3, we can compute the difference between the midnight and midday noise factors, f_{an} and f_{ad}, respectively. Table 4 shows this difference (f_{an} - f_{ad}) for the four seasons in 1999 at the RFs of 4, 5 and 6 MHz. From Table 4, we can observe that the diurnal difference was mostly around 20 dB. One exception is that, during the winter, the difference was around

5 dB lower at about 15 dB. The maximum difference between the noise factors at midnight and midday was 24.10 dB at the RF of 6 MHz in the summer of 1999, and the minimum difference was 14.46 dB at the RF of 5 MHz in the winter of 1999.

Table 4. The Difference Of Estimated Noise Factors (dB) At Midnight And Midday (3rd And 15th UTC Hour) In 1999

Season \ RF (MHz)	4	5	6
Spring	19.79	19.65	20.73
Summer	20.73	22.01	24.10
Fall	19.50	19.25	21.43
Winter	16.11	14.46	15.78

5. Comparison With CCIR Noise Data

The CCIR noise model is often used as a benchmark for the noise floor in the design of HF radio systems. This noise model is based on the interpolation of noise data measured at selected sites around the globe. However, for a specific radar site, we need to measure the actual external noise power level more accurately.

We first compare the CCIR data with the ESH3 scans shown in Figure 3. Here we assume that Cape Race is a quiet noise site according to the CCIR model. We superimpose the CCIR noise data on top of those measured from Cape Race at midday and midnight in Figure 6. As shown in Figure 6, the measured noise floors are actually quite close to the modeled CCIR noise data.

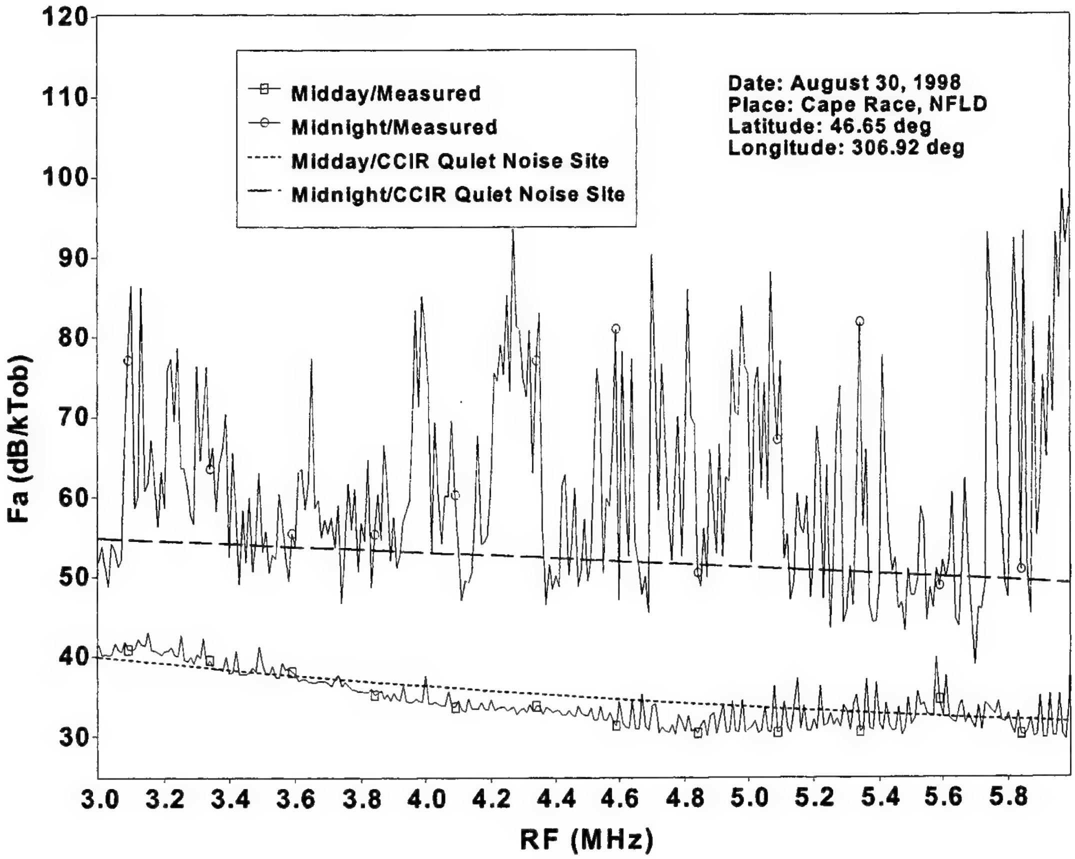

Figure 6. *Comparison Between ESH3 Scans And CCIR Noise Factors At Midday And Midnight In The Frequency Band of 3-6 MHz At Cape Race; Quiet Noise Site Is Assumed In The CCIR Model*

Next, we compare the CCIR noise factors with the measured noise factors at 4, 5 and 6 MHz. A word of caution, however, should be given before we proceed with the comparison. The CCIR noise model was developed mainly for narrowband communications, and the model is based on data measured with a bandwidth of 200 Hz [3]. This bandwidth is much smaller than the bandwidth of 10 kHz used in our measurements. A bigger bandwidth implies that, if the frequency band was congested with interfering signals, our measurement was more likely contaminated with interference. This could increase the noise floor in the measured data. During daytime, there were very few interfering signals in the frequency band of 3-6 MHz. Hence, the noise estimate from our measured data should be fairly indicative of the external noise power level. At night, however, there were many interfering signals, and our data were more likely contaminated than the CCIR data.

In general, HFSWR systems use a bandwidth in the range of 20-100 kHz. The bandwidth we used here was smaller than the bandwidth used by the radar. Hence, although our data were more likely contaminated with interference, the noise factor estimated from the data should remain fairly indicative of the noise level experienced by the radar receivers.

Figure 7 shows the estimated noise factors presented in Section 4, together with the corresponding CCIR noise factors for a quiet site at Cape Race. Several observations can be made from Figure 7:

1. The measured noise levels during daytime hours were generally lower than the corresponding CCIR noise factors;

2. The measured noise levels during nighttime hours were generally higher, likely due to more interference contamination in our measured data;

3. Daytime-to-nighttime or nighttime-to-daytime transitions observed from the noise data mostly agreed with each other. One exception was that, in the falls of both 1998 and 1999, the nighttime-to-daytime transitions in the measured noise data appeared to come about two hours earlier. Note that the daytime-to-nighttime transitions came at about the same time in both the measured and CCIR noise data.

The difference between the measured noise factor and the CCIR noise factor is listed in Table 5 for midday (15^{th} UTC hour), and in Table 6 for midnight (3^{rd} UTC hour). As shown in Table 5, all measured daytime noise levels were lower than the corresponding CCIR noise data, and the biggest difference between the measured and CCIR noise factors was 6.08 dB at the RF of 6 MHz in the fall of 1999. Similarly, in Table 6, most measured nighttime noise levels were higher than the corresponding CCIR noise data, and the biggest difference in the nighttime noise factors was 6.72 dB at the RF of 4 MHz in the summer of 1999.

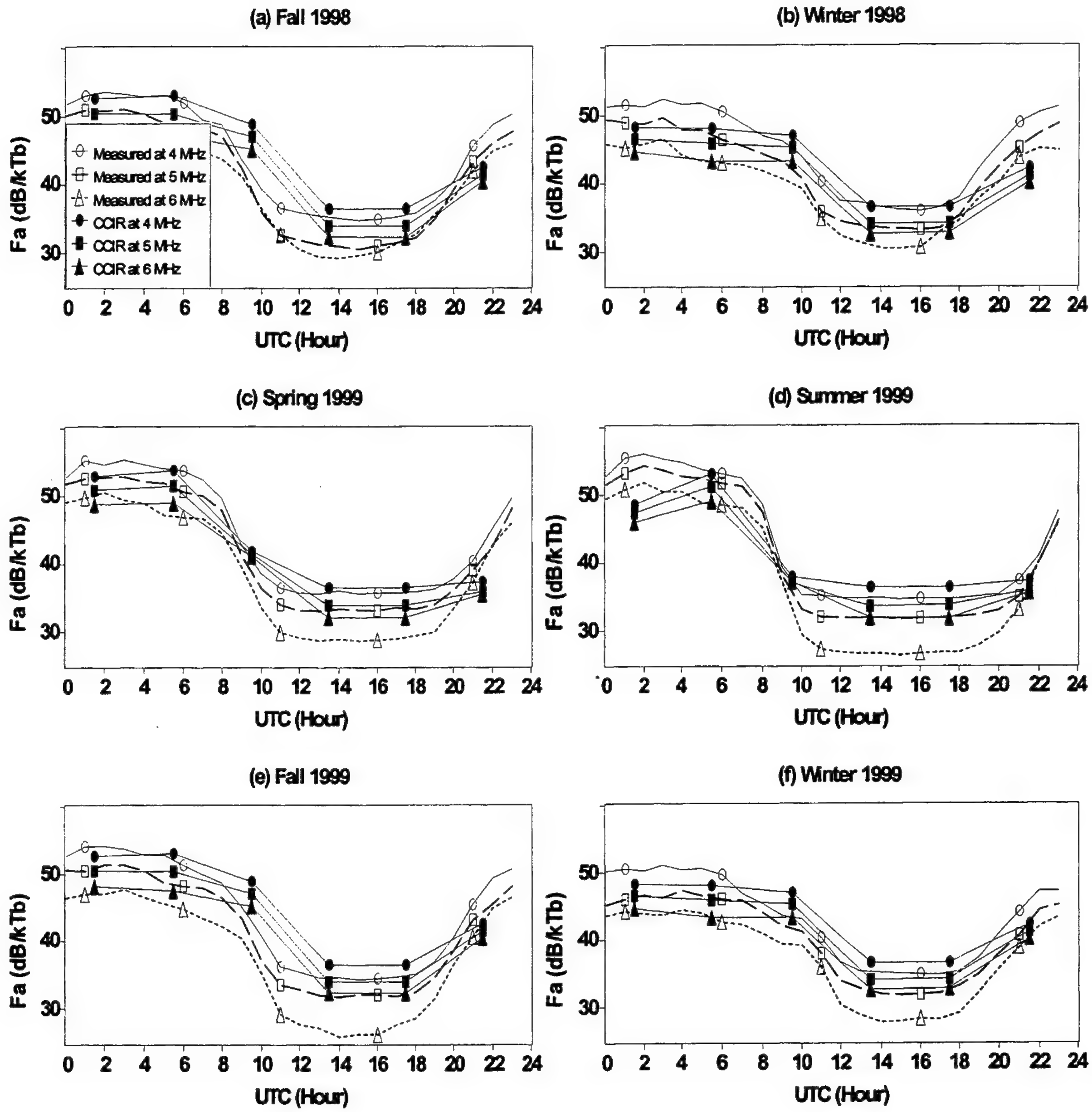

Figure 7. *Comparison Between Measured And CCIR Noise Factors At 4, 5 and 6 MHz At Cape Race; Quiet Noise Site Is Assumed In The CCIR Model*

Table 5. **Difference Between Measured (f_{am}) and CCIR (f_{ac}) Noise Factors (f_{am} -f_{ac} ; unit=dB/kT_0b) At Midday (15th UTC Hour) In 1999**

Season \ RF (MHz)	4	5	6
Spring	-0.91	-0.66	-3.36
Summer	-1.81	-1.92	-5.48
Fall	-2.21	-1.71	-6.08
Winter	-1.57	-2.35	-4.63

Table 6. **Difference Between Measured (f_{am}) and CCIR (f_{ac}) Noise Factors (f_{am} -f_{ac}; unit=dB/kT_0b) At Midnight (3rd UTC Hour) In 1999**

Season \ RF (MHz)	4	5	6
Spring	2.48	2.19	0.67
Summer	6.72	6.29	4.52
Fall	1.09	0.94	0.45
Winter	2.84	-0.29	-0.95

6. Conclusions

In support of the operation of the east coast HFSWR systems, a continuous measurement of noise and interference data was carried out at Cape Race, Newfoundland between August 1, 1998 and May 10, 2000 in the frequency band of 3-6 MHz. By using a procedure developed in this report, we estimated the noise factors at the RFs of 4, 5 and 6 MHz from the measured data over six consecutive seasons in 1998 and 1999. The estimated noise factors showed:

1. There was a marked diurnal variation in the noise data. The nighttime noise power level could be as much as 24.1 dB above the daytime noise level.

2. There were also seasonal variations in the noise data.

   (a) Daytime noise level was sustained for more than 10 hours during the summer, whereas daytime noise level was sustained for about 6 hours only during the winter.

   (b) Nighttime noise level was higher during the summer, and lower during the winter. However, daytime noise level showed little variation over the four seasons. The maximum difference of the noise levels between the two seasons at midnight was 7.38 dB at the RF of 5 MHz between the summer and winter of 1999. The maximum difference of the noise levels between any two seasons at midday was 2.42 dB. This happened at the RF of 6 MHz between the spring and fall of 1999.

The set of measured noise data confirms that the radar systems achieve the best performance during daytime hours. Furthermore, this best performance can be sustained for four hours longer during the summer than during the winter.

The measured noise factor was then compared with the CCIR noise data for a quiet noise site. From this comparison, we found that:

1. The measured noise factor during daytime hours was generally lower than the corresponding CCIR noise factor; the biggest difference in the daytime noise factors was 6.08 dB at the RF of 6 MHz in the fall of 1999.

2. The measured noise factor during nighttime hours was generally higher, likely due to the fact that we used a broader measurement bandwidth; the biggest difference in the nighttime noise factors was 6.72 dB at the RF of 4 MHz in the summer of 1999.

3. Daytime-to-nighttime or nighttime-to-daytime transitions in the noise data mostly agreed with each other. One exception was that, in the falls of both 1998 and 1999, the nighttime-to-daytime transitions in the measured noise data appeared to come two hours earlier.

Our results indicate that, during daytime hours, we can expect slightly better performance from the two HFSWR systems than that indicated by the CCIR noise data. At night, however, the radar performance could be degraded due to the presence of interference. The earlier nighttime-to-daytime transition in the fall, as observed in the falls of 1998 and 1999, is beneficial to the radar operation in that the radar systems could achieve their daytime performance for about two hours longer.

References

1. International Radio Consultative Committee, "Characteristics and Applications of Atmospheric Radio Noise Data", CCIR Report 322-3, International Telecommunication Union, Geneva, 1988.

2. A. M. Ponsford, Private Communications, Raytheon Canada Limited, November, 2000.

3. International Scientific Radio Union, "The Measurement of Characteristics of Terrestrial Radio Noise", URSI Special Report No. 7, Elsevier Publishing Company, London, UK, 1962, p. 48.

Appendix A Calibration of Noise Monitor

1. Antenna Calibration

The antenna used for the Cape Race noise monitor was a Shakespeare model 393, 23 foot SSB fibreglass antenna with no loading coil. It was installed with 32 base copper radials (#12 wire, 15 m long) as a ground screen.

A proper antenna analysis requires the consideration of an equivalent circuit for the antenna. Figure 1 shows the equivalent circuit used by Northern Radar [1]. This circuit contains the following parameters:

R_a = Antenna radiation resistance
R_g = Ground resistance
X_a = Antenna reactance to ground
R_b = base resistance
X_b = base reactance
Z_b = base impedance = R_b+jX_b
R_L = receiver resistance (50 Ohms)

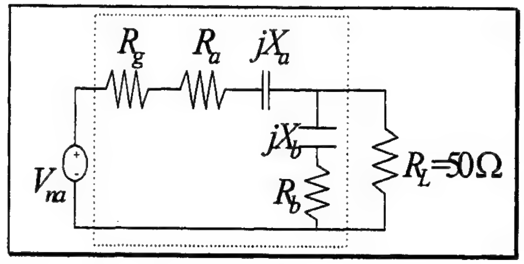

***Figure 1.** Equivalent Antenna Circuit*

The antenna input impedance, $Z_{in}=R_{in}+jX_{in}$, is the parallel connection of Z_b with $Z_a = R_a + R_g + jX_a$. Using an impedance analyser, the input impedance, as well as the base impedance Z_b, can be measured. The measurement of Z_b can be achieved by simply disconnecting the lead to the antenna. The antenna impedance, Z_a, can be extracted from Z_{in} by subtracting the base susceptance, $Y_b = 1/Z_b$, from the input susceptance, $Y_{in} = 1/Z_{in}$, i.e.,

$$Y_a = 1/Z_a = Y_{in} - Y_b \tag{A1}$$

Figures 2, 3 and 4 show the above described impedances for the 23 foot whip antenna. In Figure 2 are the base resistance and reactance, in Figure 3 are the antenna input resistance and radiation resistance plus the ground resistance, and in Figure 4 are the input reactance and the antenna reactance. These measured values are used in the calibration procedure described below.

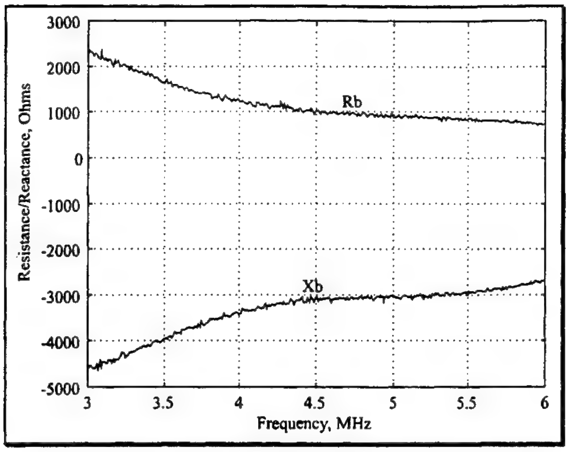

Figure 2. Base Impedance

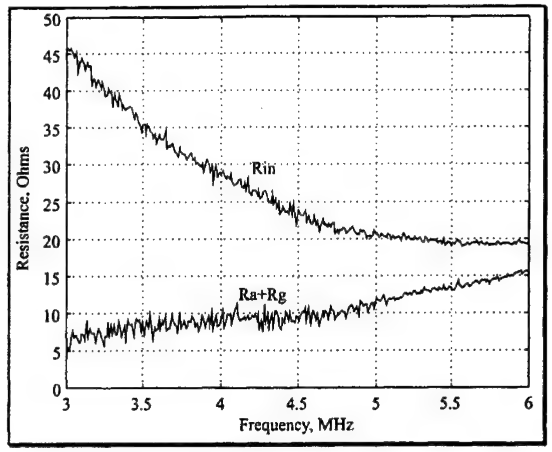

Figure 3. Input and Antenna Resistances

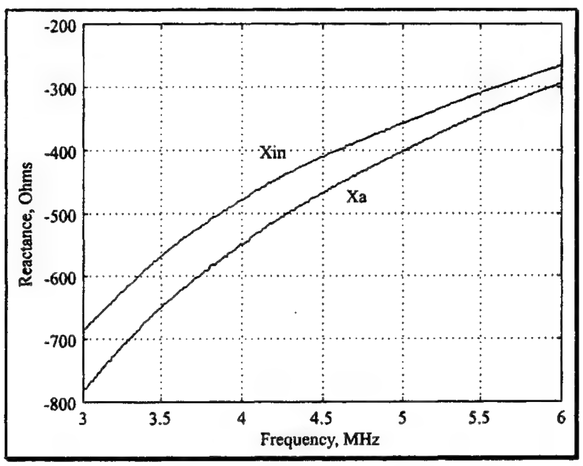

Figure 4. Input and Antenna Reactances

Calibration Procedure

The whip antenna can be calibrated by using the equivalent antenna circuit. The available root-mean-square noise voltage (open circuit) can be measured at the base of the antenna and is given by the following [2]:

$$V_{na} = 2\sqrt{KT_a R_a B} \tag{A2}$$

where T_a is the equivalent antenna noise temperature (K), K is Boltzmann's constant (J/K), R_a (Ohms) is the antenna radiation resistance and B (Hz) is the measurement bandwidth. The voltage across the load (receiver) resistor, V_L, can be calculated using a voltage divider:

$$V_L = \frac{Z_{eq} V_{na}}{R_a + R_g + jX_a + Z_{eq}} = \frac{Z_{eq} V_{na}}{Z_a + Z_{eq}} \tag{A3}$$

where Z_{eq} is the parallel impedance of R_L and Z_b:

$$Z_{eq} = Z_b R_L / (Z_b + R_L) \tag{A4}$$

Therefore, the noise power to the receiver is given by

$$P_L = |V_L|^2 / R_L = \frac{4R_a}{R_L} \left| \frac{Z_{eq}}{Z_a + Z_{eq}} \right|^2 (KT_a B) \tag{A5}$$

Note that if matched lossless conditions exist (R_L=R_a, R_g=0, X_a=0, X_b=R_b=∞) then the power to the receiver is

$$P_L = \frac{4R_a}{R_a} \left| \frac{R_a}{2R_a} \right|^2 (KT_a B) = KT_a B = P_{na} \tag{A6}$$

which equals the noise power from a lossless, perfectly matched antenna. Note that the noise factor, f_a, is defined [3] as:

$$f_a = \frac{P_{na}}{KT_0 B} = \frac{KT_a B}{KT_0 B} = \frac{T_a}{T_0} \tag{A7}$$

where T_0 is standard temperature (290 K) and T_a is the antenna noise temperature.

We use the following notation in the case of a lossy, unmatched antenna, such as the 23 foot whip antenna at Cape Race:

$$P_L = MP_{na} \tag{A8}$$

where M is the loss factor given by

$$M = \frac{4R_a}{R_L} \left| \frac{Z_{eq}}{Z_a + Z_{eq}} \right|^2 \tag{A9}$$

2. Amplifier Calibration

The gain of the pre-amplifier (ZHL-1A) has been measured with a vector network analyser and the linear gain of the pre-amplifier is plotted Figure 5. Note that the average gain of the pre-amplifier is 18.5 dB.

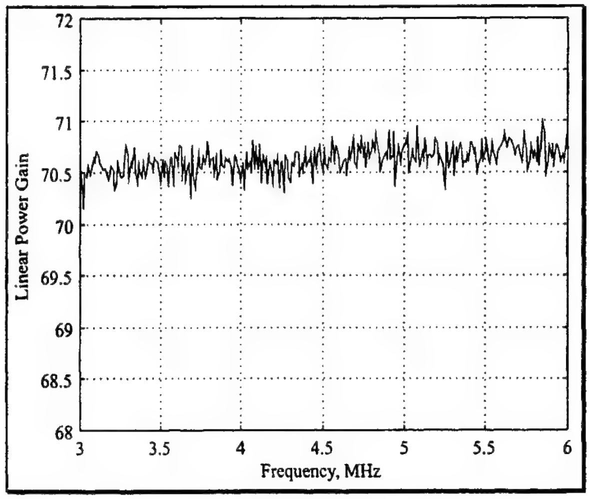

Figure 5. *Power Gain Of Pre-Amplifier ZHL-1A*

The internal noise floor of the noise monitor, P_{nr}, can be obtained by placing a 50 Ohm resistor at the amplifier input. This produces the matched conditions, from which the system noise, P_0, can be measured. This system noise consists of the internal receiver noise P_{nr} and the amplified 50 Ohm resistor noise $P_{ar} = AKT_0B$, where A is the amplifier gain. We can determine the internal receiver noise level by subtracting the amplified resistor noise from the measured system noise P_0:

$$P_{nr} = P_0 - P_{ar} = P_0 - AKT_0B \tag{A10}$$

At the bandwidth of 10 kHz, the system noise P_0 is -108 dBm.

The total noise power received by the system when it is connected to the antenna is given by

$$P_{n0} = AP_L + P_{nr} = AMP_{na} + P_0 - AKT_0B \tag{A11}$$

The quantity that we require is the external noise power, P_{na}. By solving the equation above, we have:

$$P_{na} = \frac{1}{M}\left[\frac{P_{n0}}{A} - \left(\frac{P_0}{A} - KT_0B\right)\right] \tag{A12}$$

which we can then use in Equation (A7) to calculate the noise factor

$$f_a = \frac{P_{na}}{KT_0B} = \frac{1}{M}\left[\frac{P_{n0} - P_0}{AKT_0B} + 1\right] \tag{A13}$$

3. Cable Attenuation Correction

The cable out to the antenna is approximately 160 feet long and introduces an attenuation that must be corrected. This cable attenuation has been measured and is plotted in Figure 6.

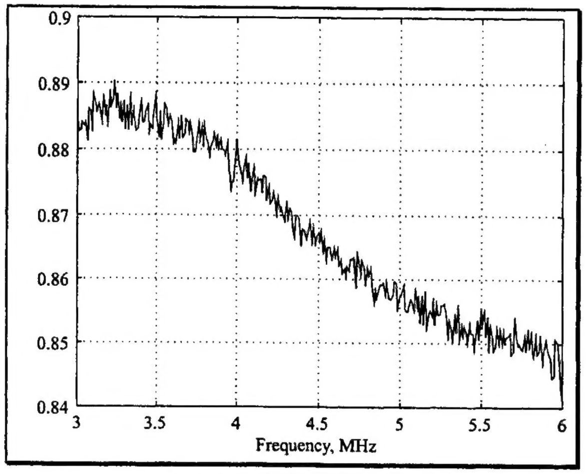

Figure 6. *Cable Attenuation, L_C*

To account for this cable loss, we simply replace the loss factor M in Equation (A9) with the following:

$$\tilde{M} = ML_C \tag{A14}$$

Where L_C is the cable loss factor and $\tilde{M}$ is the corrected loss factor.

References

1. Northern Radar, "Verification of the Performance of the Cape Race Transmitting and Receiving Antennas, Technical Report Number NR-AF00A-R01, December 1997.

2. R. E. Colin, "Antennas and Radiowave Propagation", McGraw-Hill Book Company, 1985, pp 312-315.

3. International Radio Consultative Committee, "Characteristics and Applications of Atmospheric Radio Noise Data", CCIR Report 322-3, International Telecommunication Union, Geneva, 1988.

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In support of the operation of the east coast High Frequency surface wave radar (HFSWR) systems, a continuous measurement of noise and interference data in the frequency band of 3-6 MHz was carried out at Cape Race, Newfoundland between August 1, 1998 and May 10, 2000. A procedure called the "minimum of median" was developed to estimate the noise factors from the measured data. The results of the estimation are presented in this report. This estimation showed that (a) nighttime noise power level could be as much as 24.1 dB above daytime noise level; (b) daytime noise level could be sustained for more than 10 hours during the summer, but only for about 6 hours during the winter. The estimated noise factor was then compared the CCIR noise factor for a quiet site [1]. From this comparison, we found that (a) the daytime noise power level could be as much as 6.08 dB lower than the corresponding CCIR noise level, and (b) the nighttime noise level could be as much as 6.72 dB higher than the corresponding CCIR noise level. The transitions from daytime to nighttime or from nighttime to daytime in the measured and CCIR noise data agreed mostly with each other. One exception was that, in the falls of both 1998 and 1999, the nighttime-to-daytime transition in the measured noise data was about two hours earlier.

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High Frequency Surface Wave Radar (HFSWR)
HF Noise
Diurnal Variation
Seasonal Variation
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